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14. ABSTRACT

The Virtual Parts Engineering Research Initiative, begun by the Army Research Office in 2001, has developed and matured through Hampton University's Virtual Parts Engineering Research Center (VPERC) and through the collaboration of two sister institutions, University of Utah and Arizona State University. These efforts and these institutions have been dedicated to the development of a virtual platform that provides for expeditious and economical development of spare parts for legacy military weapons systems. Hampton and its academic partners responded to those needs by developing a capability to capture the technical data essential to the manufacture of a given part via NC equipment. In fact, the goals and the successes achieved

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Report Title

Virtual Parts Engineering Research Center Initiative

ABSTRACT

The Virtual Parts Engineering Research Initiative, begun by the Army Research Office in 2001, has developed and matured through Hampton University's Virtual Parts Engineering Research Center (VPERC) and through the collaboration of two sister institutions, University of Utah and Arizona State University. These efforts and these institutions have been dedicated to the development of a virtual platform that provides for expeditious and economical development of spare parts for legacy military weapons systems. Hampton and its academic partners responded to those needs by developing a capability to capture the technical data essential to the manufacture of a given part via NC equipment. In fact, the goals and the successes achieved thus far are to develop parts totally within a virtual environment from the derivation of the technical data file through procurement to manufacture by CAM. The goals have been largely achieved and demonstrated through the development of several proofs-of-concept with varying complexities and developmental environments. This report describes some of the parts developed under the project, past and present, their metrics, manufacturing processes and lessons learned.

List of papers submitted or published that acknowledge ARO support during this reporting period. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

Number of Papers published in peer-reviewed journals: 0.00

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Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts): 0

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Number of Inventions:

Graduate Students

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Post Doctorates

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Faculty Supported

NAME	PERCENT_SUPPORTED	National Academy Member
Dr. Vadivel Jagasivamani	0.50	No
Dr. Amir Chegini	0.50	No
Dr. Tuba Bayraktar	0.25	No
FTE Equivalent:	**1.25**	
Total Number:	**3**	

Names of Under Graduate students supported

NAME	PERCENT_SUPPORTED
TaVon Reynolds	0.25
Everett Corbin III	0.25
Latisha Howard	0.25
Victor Miano	0.50
Devona Thomas	0.20
Carla Lillard	0.20
John Jones	0.50
Brandon Fox	0.30
Josh Crenchaw	0.50
Sidney Phinazee	0.15
FTE Equivalent:	**3.10**
Total Number:	**10**

Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period: 4.00

The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:...... 4.00

The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:...... 2.00

Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):...... 0.00

Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense 0.00

The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields:...... 0.00

Names of Personnel receiving masters degrees

NAME

Total Number:

Names of personnel receiving PHDs

NAME

Total Number:

Names of other research staff

NAME	PERCENT_SUPPORTED	
Ronald Jefferson	0.50	No
Gerald Swenson	0.50	No
FTE Equivalent:	**1.00**	
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Scientific Progress and Accomplishments

1. Introduction

Many US military systems that were designed and manufactured up to fifty years ago are still usefully serving the nation. However, continued successful use of these systems is possible only if manufacturing the necessary spare parts for periodic maintenance of the systems is possible. Most of these parts are mechanical and electromechanical types that do not carry the necessary documents to permit efficient, economical remanufacturing. The US armed services are well aware of the difficulties involved in prolonged maintenance of these valuable units and are promoting an initiative for parts procurement for the Army that is directed toward the issues related to legacy systems.

Hampton University received support from the Army Research Office to perform R&D work at the University to support the procurement of parts for legacy systems under grant number W911NF0510164. The major task the University undertook is to develop an efficient process for parts procurement for legacy systems and develop techniques for quality assurance and safety. Hampton University has developed the necessary infrastructure to aid manufacturing of parts on-demand, has constructed in-house R&D and testing facilities to carry out data acquisition and failure analysis, and has engaged in collaborative research in developing and demonstrating more effective techniques to aid in reverse engineering and reengineering of parts reliably, rapidly and cost effectively.

Hampton University established a center for parts engineering at its Hampton, Virginia campus and named it the Virtual Parts Engineering Research

Center (VPERC). Its physical activities of the Center have been carried out at the Data Conversion and Management Laboratory (DCML) and in the School of Engineering and Technology. VPERC developed a web-based manufacturing infrastructure in collaboration with South Carolina Research Authority (SCRA) that can be accessed through the Internet. In collaboration with the University of Utah and Arizona State University, Hampton University performed data handling and reverse engineering tasks to identify areas of focus and to suggest optimum solutions to the problem areas encountered.

This document lists some of the issues identified, some of the activities carried out and solutions proposed to handle the parts procurement initiative for maintaining legacy systems. Documents in the appendices show some of the experimental efforts taken to demonstrate the effectiveness of the VPERC process and applications of ultrasonics to complement the conventional methods of reverse engineering efforts.

A VPERC web site has been established at http://www.vperc.org, developed to exchange information among the collaborating Universities, manufacturers and government agencies.

2. Parts Requirements for the Army

Legacy defense systems designed and manufactured decades ago are still serving the Army satisfactorily in warfare including service in the Middle East and Afghanistan. The reliability of these units is mostly dependent on proper maintenance and periodic replacement of worn out and damaged parts. Obviously, the supply of spare parts in warfare is very critical, causing immobility and hence, vulnerability for the soldiers unless the right tools and the right parts are delivered when they are needed. There are cases in recent wars where soldiers had to improvise the required parts from what is available locally or to pirate other weapons systems, but even such compromised measures are not always possible and as a result, the solders are put in a disadvantageous and dangerous position.

A Mobile Parts Hospital (MPH), a self contained transportable mini-manufacturing facility coupled with a communication control center, has been developed by the Army Materiel Command and has been successfully used to machine parts for the Army at the site of the warfare. MPHs, in a constant need for parts and parts needs, communicate among themselves and within the Army's database for parts information. These units are capable of machining parts on demand in a short time frame. Two MPHs have been serving in Kuwait in support of the Iraq war, operating in 16 hour shifts to keep up with the demand and have machined parts such as bolts, brass studs, pulleys, etc. for M88/1790 engines, M2 Bradley engines, HEMTT 8V92TAs and HMMWV engines and differentials (1).

There are also cases where soldiers have received custom designed and built subassemblies such as gun mounts with swivel capability to perform their job more effectively. Rapid Manufacturing System (RMS) operating out of Kuwait is able to meet such custom built accessory requirements very effectively.

Fifty years ago when some of these units were built, system manufacturers did not routinely accumulate documents from all their subcontractors for subsequent inclusion in a comprehensive technical data package for delivery to the Army along with the manufactured units. Most of the manufacturers did not store them for extended future use. Some manufacturers do not even exist today. And there are manufacturers who are not willing to share the information on manufacturing methods used, then or now. In some cases, some manufacturers do not exist at the present time. Consequently, when the originally supplied spare parts have been consumed the Army has to resort to reverse engineering of what parts are left so that valuable legacy systems can continue to serve the Army.

In those cases where technical information does exist, sufficient documents may not be available to be able to assure accurate machining or manufacturing. And in other cases, it may be more appropriate to modify the design to perform better.

All these activities taking place at a time of armed conflict clearly identifies the need for a better infrastructure and technology to perform rapid parts production with the capability to manufacture parts in small quantities and on demand.

As a result of this lack of technical data there is a strong demand for reverse engineering and reengineering initiatives to be carried out for the Army in order to supply parts. Many of the reverse engineering efforts currently are carried out on site, relying on the skill of the engineer and machinist who decide the selection of materials and manufacturing processes based on his past experience. These approaches have helped to meet the fast growing demand for the parts; however a scientific and systematic process needs to be developed to perform the reverse engineering task more reliably and professionally.

3. Approach to Parts Procurement for Legacy Systems

3.1. Traditional process for procurement of parts

Traditionally, manufacturing data packages were prepared as engineering drawings and printed instructions and stored in paper form or in various forms of microfilm. Engineering data on the parts for the legacy systems may also be in C4-raster electronic format. Generally it is recognized that the raster drawings have a considerable number of errors, which in most of the cases are identified during the manufacturing processes, in which case the corrections need to be approved by authorized personnel and implemented in the drawings, a process that may well not be accomplished. In fact, among a group of three drawings that Hampton received from a defense organization, two of them carried errors such as an inner diameter larger than the outer diameter of a ring. It is generally judged that the process of manufacturing directly using the C4 drawings will result in the consumption of a considerable amount of time and effort, precious commodities when the manufacturing effort is directly supporting the troops in the field. VPERC has identified these problems and has made great strides in developing a parts manufacturing process with Web-based interaction for rapid procurement of the parts.

3.2. Standardization of Data Format for Parts Procurement

There are several CAD vendors in the industry with CAD data exported in proprietary formats which cannot be interpreted by the users of other CAD packages. This makes it very difficult to exchange data among the users of different CAD software. And the process of converting formats or translating may not be satisfactory to reveal all the features of a given part correctly.

Globalization of manufacturing is expanding rapidly and there is a need for an international standard for representing product data. The International Organization for Standardization (ISO) and American National Standards Institute (ANSI) are promoting STEP application protocols (Standard for Exchange of Product Model Data) as a way to standardize the representation of product data models. Currently most of the popular CAD packages have the capability of importing and exporting some of the STEP application protocols, paving the way to the standardization of product model through STEP (Figure 3.1) and thereby reducing the burden on reworking CAD models when CAD systems or data processing systems change.

In collaboration with Arizona State University, Hampton University has explored methods of deducing machining features from AP203 files and has researched the possibilities of generating AP204 files for parts. The efforts put forth were successful for parts with simple geometrical features (Figure 3.8)

CNC machines for manufacturing parts have been popular for the past forty years in the industry. These machines need machining instructions programmed in appropriate CNC codes. Currently STEP practitioners are encouraging the development of STEP-NC machines which take STEP files more readily and comprehensively and thereby reduce the cost of programming for each manufacturing activity.

All these efforts help introduce “lean” manufacturing efforts into the manufacturing industry.

3.3. VPERC Process for Parts Procurement

VPERC technology uses the Internet for communication between different groups involved in the manufacturing process. Once the part is captured in CAD and exported as a STEP file into a repository, the system is designed to permit acquisition of a given part's technical data in a very short period of time.

The end-user of the part may identify his needs by searching for the part through the Internet. Once it is identified the user can then contact approved manufacturers for quotation and delivery time and the order for manufacturing can be awarded. All these are possible over the Internet without any other help or intervention. Since the data package is maintained in the repository in a form most appropriate for rapid manufacturing, the whole process provides a platform for faster acquisition of the part for the end-users (Figure 3.2).

3.3.1. Advantages of the VPERC Process

There are features associated with the VPERC process that are advantageous to the parts procurement effort.

For example, the data is stored only after several quality checks and therefore the end product will be almost defect-free. The process results in a fewer rejections during the manufacture, the part will be more economical and the production will take less time to complete. Since the data files have been stored electronically, process planning and CNC coding will make use of the advantages of electronic format and the programming will introduce less human errors.

The process is most appropriate for the production of parts in small quantities, since the savings on process planning and CNC coding are greater with

STEP AP224 files. Finally, the electronic process and product encourages increased globalization in manufacturing.

3.4. Remanufacturing Parts for Legacy Systems

The remanufacturing of parts for legacy systems falls into three major categories: reverse engineering, reengineering and redesign. When it is required that functionality needs to be added to an existing part, the process of redesign can provide added features, better materials and/or better manufacturing processes.

REVERSE ENGINEERING	REENGINEERING	REDESIGN
No documents available	Documents may be available.	Identification of parts of typical nature used in industry.
Take physical measurements and build necessary document or data file.	Improved materials may be used. Restricted materials will be avoided.	Identification of features that can be improved
Mostly original materials and manufacturing methods will be adopted	Improved manufacturing methods will be used if possible.	Identification of suitable materials and manufacturing method
	New features may be added to widen the performance and the applications of the part	

Table 3.1 Guidance to select the various processes of remanufacturing

If a part is found to fail too often, the process of reengineering can be carried out to improve the reliability and life of the part. Furthermore, if the materials and processes that originally went into the development of the part are not appropriate for today's manufacturing technologies, reengineering the part will permit the application of appropriate processes and materials.

3.5. Reverse Engineering Process Setup at HU for Legacy Systems

3.5.1. Reverse Engineering Process

Parts that are required to be duplicated without any change in features or functionality are subjected to reverse engineering. Reverse engineering is practiced with different kinds of tools and facilities; however, the process is almost the same as with the original part's development, namely, understanding the functionality associatively with other parts in an assembly, deducing the geometry and dimensions, identifying the materials, processes and manufacturing processes, arriving at a possible quality assurance method and finally projecting the necessary maintenance procedures.

The possible tasks involved in the reverse engineering process may include:

1. Identify the functions
2. Identify each component in an assembly
3. Perform failure analyses to prevent failures
4. Check for availability of ready-made pieces (bearings / shafts/ gears / fasteners, subassemblies)
5. Fabrication methods
6. Identify manufacturers
7. Select Materials
8. Identify treatments

9. Identify testing/evaluating methods especially for parts used in critical applications. Possibilities of embedding NDT sensors in parts may be explored.

10. Establish maintenance and test procedures

The actual process of reverse engineering, however, will depend on the quantity of parts manufactured, cost of manufacture, time constraints to complete the process and finally whether the part is used in sensitive or critical applications.

3.5.2. R&D facility for Reverse Engineering at Hampton University

A collection of advanced research instrumentation and equipment has been acquired for the VPERC Lab in order to more effectively pursue reverse engineering of mechanical and electromechanical parts. A laboratory space of 30' x 50' was allocated in the Olin Engineering building of the School of Engineering and Technology to house the VPERC Lab. Research equipment consists of optical microscopes, scanning electron microscope, X-ray diffraction unit, specimen preparation units, coordinate measuring machine, universal mechanical testing machines, ultrasonic units, a mechanical measuring unit and an electronic measuring unit with data acquisition capabilities. The list of units acquired and their applications in reverse engineering efforts are given in table 3.2. These units are also intensively used by research students of science and engineering programs in Hampton University. At present, three courses offered in the School use the VPERC laboratory facilities extensively to carry out classes. Table 3.3 lists the concepts the students derive by carrying out the laboratory assignments. In addition researchers regularly carry out such activities as X-ray diffraction studies, nano-materials structure studies, and development of catalysts using the laboratory facilities and equipment of VPERC.

Facility	Units	Applications
CMM	XSpect	Measurement and preparation of CAD
CAD	STEPTrans and STEPValidator (SCRA)	Exports STEP AP-224, rapid process planning and CNC coding, ideal for lean manufacturing
Structural Analysis	ANSYS	Structural and Thermal Analysis
Microscopy	JEOL SEM with EDX for elemental analysis	Fracture studies, elemental analyses, metallography
	LEITZ Optical Microscope	Metallography, Failure analysis
Mechanical testing	Instron Universal testing machine	Mechanical properties and strength of materials
X-ray Diffraction	Panalytical XRD with phase identifications and stress analysis	Identification of phases, residual stresses
Ultrasonics	Matec Ultrasonic scanner	Measurements of features, classification of materials, NDT

SEM – Scanning electron microscope EDX – Energy dispersive X-ray analysis XRD – X-ray diffraction
SCRA – South Carolina Research Authority NDT – Nondestructive testing

Table 3.2 Equipment to support Reverse engineering

Title	Recommended prerequisites	Learning aspects
Tensile testing	Stress – strain Elastic modulus	1. Elastic modulus 2. Stress – strain curve 3. Deformation in brittle and ductile materials 4. Toughness, cold-working, necking
Ultrasonic testing	Ultrasonics in NDT & Physics	Acoustic properties in materials Modes of vibration Determination of velocity, length, elastic modulus NDT applications
Microscopy (Optical & SEM)	Grain structure, phase diagram, heat-treatment	1. Optical microscopy 2. SEM 3. Specimen preparation methods 4. Metallography and Structure studies 5. Failure analysis
X-ray Diffraction	Crystallography Bragg's law Powder method	X-ray diffraction unit Powder method Identification of structure Identification of materials Residual stress studies Texture studies (with limitations)
Strain gauge measurements	Strain gauge instrumentation, Load cell, Carrier frequency amplifiers	Strain gauges Instrumentation Data acquisition

Table 3.3 List of experiments developed for engineering courses offered in the School of Engineering.

3.5.3 Application of Ultrasonics in Reverse Engineering Efforts

Several scientific instruments are used as tools in reverse engineering efforts. Some of these instruments have been developed specially for applications in reverse engineering to help in collecting dimensions and shapes of the three dimensional parts. Ultrasonic instrumentation is widely used in nondestructive testing (NDT) and in materials research. It is successfully used in the measurement of thickness of materials with access from just one side of the object. Basically ultrasonic methods of testing rely on the acoustic and elastic properties of the materials. With some basic understanding of the principles and techniques of testing, ultrasonic methods can provide data on mechanical measurements that are sometimes not available through conventional methods.

Hampton University has developed a technique to acquire geometry and dimensions from parts using an ultrasonic scanner (Figure 3.3), during phase I efforts. The part is subjected to C-scan, wherein an ultrasonic probe executes an X-Y raster scan on the part with the part immersed in water. During the scan the instrument collects A-scan data as shown in figure 3.4. Depending on the presence of features in the part at different depths, gates are set to extract reflection data from the A-scan and the C-scan image is built. Figure 3.5 shows the C-scan images collected at different depths from a ring part. All the data are collected in a single scan.

Hampton has also developed a new ultrasonic technique to evaluate the surface finish of machined parts in a non-intrusive manner. The technique employs a pair of ultrasonic probes positioned in appropriate orientation, one for sending sound wave and another to collect the scattered sound waves from the machined surface. A model has been developed to correlate the frequency spectrum of the scatter to the roughness of the surface [4].

3.5.4 Materials Identification for reverse engineering

There are a wide range of materials available for different applications. High-end engineering units use more and more high-technology materials, which cannot just be replaced with a general purpose engineering materials. High strength alloys, composites (polymer composites and metallic composites), materials undergone special treatments, etc. have to be identified properly and a suitable material can be proposed.

Some materials may need suitable heat-treatment to bring out the best properties. If the information on the material is not available, it is essential to resort to systematic material analyses to be able to arrive at informed decisions. When a part fails prematurely it is essential to investigate the cause of failure and apply the necessary modifications in the design. End-users' feedback should be given due consideration as a factor in deriving appropriate changes in the design.

3.5.5 Treatment Processes

Heat treatment and mechanical treatment are applied to finished products to improve the performance of the part either in wear resistance, durability or strength. Effectiveness of heat-treatment can be verified by conducting detailed metallographic studies or by simple hardness testing. If necessary, recommendations for such tests can be made a requirement defined in the part's specifications to ensure quality.

3.5.6. Manufacturing Processes

Parts can be manufactured by different methods. The performance of the part depends on the method used. Forming methods, such as forging or rolling generally provide superior performance. Casting methods are highly useful in achieving complex shapes with rigidity. Machining methods provide higher dimensional accuracy. Sometimes welding or metal joining methods are specified to achieve parts of complex shapes. It is necessary to identify the most appropriate method for a task.

3.5.7. Quality Assurance Methods and Developing Maintenance Procedures.

Quality assurance and nondestructive testing are useful to ensure the integrity and safety of the product. Nondestructive testing is widely used to certify critical parts. Original design of parts should adopt a consideration for allowing easy access for nondestructive testing. One way this can be achieved is by providing the necessary features and preparations on the parts to mount test probes. NDT procedures can be made easier and be carried out more frequently with the incorporation of innate NDT tooling thus enhancing safety of operation.

"Smart" structural parts are gaining importance in this way also, where the parts may permanently carry a sensor or two or even a whole instrumentation package to carry out periodic testing with the least effort on the part of the operator.

Parts put in service should be periodically inspected for condition thereby avoiding catastrophic failure during the service. The reverse engineering task should consider this aspect and propose methods of inspection at appropriate intervals.

4. Reverse Engineering and Research Efforts

In collaboration with University of Utah and Arizona State University, Hampton University has engaged in developing techniques and in improving the process of reverse engineering of parts for legacy systems using the advanced facilities of the

VPERC Lab. This Lab promotes in-house research and development exercises using this focus and engaging in carrying out reverse engineering and re-design tasks for Defense Logistics Agency (DLA).

One of the initial exercises carried out by the Lab involved an airspeed indicator gauge casing from a T38 aircraft that was received from the DLA for possible studies to reverse engineer. Figures 4.1 and 4.2 show the photographs of the part received from the DLA, with its flange partly missing. The part was manufactured originally by plastic molding using Bakelite. Plastic molding is generally more economical only manufacturing in large quantities. At VPERC we attempted to manufacture the part by machining, accomplished in collaboration with the University of Utah and Arizona State University. Two parts were remanufactured at the advanced parts development facilities at the University of Utah; another was made at the advanced machining facilities of the educational/engineering institution named Focus:HOPE, located in downtown Detroit. The first part was generated by a Fused Deposition Modeling unit (3D plastic model printer), and was therefore manufactured without the need for developing any special machining tool (Figure 4.5. The second piece was machined in a CNC machine using specially fabricated tools to handle deep machining in narrow regions (Figure 4.7). Focus:HOPE also manufactured the part by CNC machining (Figure 4.6) The technical data package, equipped for direct insertion into the CNC units, was prepared at Hampton University, subsequently receiving acceptance by the DLA (figure 4.8).

As a second major task, the researchers at Hampton's VPERC Lab carried out reverse engineering efforts on parts for a turbo-charger, received from a Defense Department agency. Dimensions were acquired and the necessary drawings were prepared to enable the development of a cost estimate. Many parts in the turbocharger are subjected extreme service conditions; these were studied for structure and composition on optical microscope, scanning electron microscope and EDAX system (figure 3.7) to identify the material and the structure. Ultrasonic tests (figure 3.3) were performed on castings to develop a database for future applications.

Structural and thermal studies on some of the parts have been carried out using the ANSYS packaged application. The part received from DLA, the airspeed indicator gauge casing was used for analysis. Figure 4.9 shows the mesh generated for the 3D model; thermal and structural analyses were performed on the model to identify the regions of thermal stresses and stress-concentrations with specific kinds of external loads (Figure 4.10, 4.11).

A new ultrasonic technique was developed to identify the surface nature of machined parts in a non-intrusive manner (Figure 4.12). A theoretical model was developed to characterize the scratch width and scratch depth of the surface and these results were presented in a QNDE conference held in July, 2005 [4].

The X-ray diffraction unit is being used to identify texture or preferred orientations in materials. Texture in materials is a significantly important factor to consider in some special applications (Figure 4.13). Also, XRD studies are being carried out to identify residual stresses in parts. Residual stresses may cause premature fatigue failure in parts which can be eliminated by appropriate heat-treatment.

Undergraduate courses offered to our engineering students, have been enhanced by incorporating laboratory exercises and research practices which are made possible with the VPERC Lab's infrastructure. Directly supported coursework includes: Manufacturing Technology (ELN469), focusing on different manufacturing methods and modern approaches to handle issues related to lean manufacturing of engineering parts; Engineering Graphics (EGR201) makes use of the infrastructure of the VPERC laboratory to educate engineering students in CAD/CAM; and Engineering Materials (EGR303), a course on materials engineering which has an accompanying laboratory session. This session makes use of facilities such as metallography, X-ray diffraction, mechanical testing and ultrasonics. Electronic Engineering Design courses (ELN409 and ELN413) make use of the VPERC infrastructure to carry out the development of sensors and transducers. In addition to these efforts, the possibilities of adding new technical elective courses in the area of materials testing, X-ray diffraction and nano-materials are being considered.

Adhesive bonding is one of the contemporary processes used in the manufacturing industry. An adhesive bond provides excellent performance in assembling parts, particularly in handling sheet metals. It reduces stress concentrations around the fasteners, resulting in reduced corrosion and fatigue damage. However, the bond may deteriorate from exposure to extremes of environmental conditions during service. For critical applications it becomes necessary to develop techniques to monitor and pre-warn impending failure of structures employing adhesive bonds. Research efforts have been carried out elsewhere to detect and evaluate the integrity of adhesive bonds; however, no satisfactory technique has evolved that will handle a variety of situations. In our research effort, we have focused our efforts on understanding the underlying mechanisms which directly influence the behavior of bonded region to assorted stresses. Adhesively bonded test samples were subjected to cycles of stresses and X-ray diffraction and ultrasonics [7] studies were carried out.

Finally, the VPERC effort has supported a collaborative project which was carried out with Arizona State University's Mechanical Engineering Department to develop techniques for remanufacturing parts for legacy systems [8]. In particular, the focus of the research was on the maintaining of original geometry and optimization of material without violating the inter-facing (geometric), functional and interfacing constraints. This involves 'TechSpec' formulation, redesign generation, design evaluation and manufacturability evaluation. TechSpec handles reference entities for building parametric models, geometric constraints, assembly, mating and spatial (size, location) relations. Design features of interest are recognized, semi-automatically or interactively, using pre-defined feature templates. The output is represented in an enhanced STEP format (OAM+) object oriented assembly model.

5. Summary and Proposed Efforts

Hampton University has identified two major roles for itself in addressing maintenance of legacy systems for the Army, namely

1. Identifying the need for developing more effective reverse engineering techniques and performing R&D activities to further this goal, and
2. Identifying alternative manufacturing methods to handle issues normally encountered with lean manufacturing.

In these efforts HU will continue to develop more effective methods of

1. Preparing technical data packages (TDP) for important parts which may be uploaded to a web-accessible server and thereby made readily available for the manufacture of parts on-demand,
2. Remanufacturing of parts for legacy systems, primarily in small quantities, for which reverse engineering may be required, and

3. Promoting collaborative research to enhance resources and creativity in arriving at appropriate solutions.

The remanufacturing effort will involve

1. Determination of mechanical and materials properties, thereby specifying the material, manufacturing procedure and subsequent treatment,
2. Developing methods of quality assurance, as the need arises and,
3. Documentation of geometry and size of parts.

Metallographic studies and mechanical testing such as hardness, wear resistance, strength, etc., are essential while reverse engineering certain parts. Specification of material and fabrication methods along with the heat-treatments to be given can be deduced from metallographic studies and the measurement of mechanical properties. Failure analyses and structural analyses play important roles if the part will be used in critical applications. Ergonomic factors along with the end-users' feedback are also very important factors in re-engineering.

In many instances engineers who perform reverse engineering carry out the work without adequate testing facilities. Manufacturing data are deduced out of their experience and knowledge they have acquired in time. This approach may be acceptable in several cases. However in modern days, newer materials, especially composites have been developed which need sophisticated equipment to carryout identification and investigation. More importantly, when it comes to the defense needs, we have the responsibility to ensure extra safety and performance in carrying out the reverse engineering service and providing a better substitute part. VPERC is continually enhancing its facilities and capabilities to carryout mechanical measurements, materials testing and failure analysis. Figure 3.6 graphically depicts our efforts in establishing advanced facilities for performing quality reverse engineering tasks.

We have a team of engineering students trained in generating 3D models, performing structural analyses and carrying out studies using materials testing units. Additionally, Hampton has the infrastructure and capability to employ professionals to conduct the job of reverse engineering when demand increases. Figure 3.7 shows the proposed process to carry out the reverse engineering effort. We have two primary channels for conducting reverse engineering efforts: The Data Conversion and Management Lab (DCML) of Hampton University has the infrastructure and a proven track record to carry out demanding CAD development needs. The School of Engineering and Technology is equipped with advanced materials testing facilities to perform structural analysis, experimental stress analysis, materials identification, and other tests. Professional CAD technicians and mechanical engineers employed by the DCML will perform routine reverse engineering tasks, supported by the faculty and technicians at the School of Engineering and Technology who will manage complex issues. The research infrastructure at the School of Engineering and Technology has provided invaluable opportunities to our engineering students to become involved in advanced research relating to manufacturing technology.

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Figure 3.1 STEP- AP224 uses text files to detail geometry, dimensions, tolerances, materials and special notes for manufacturing.

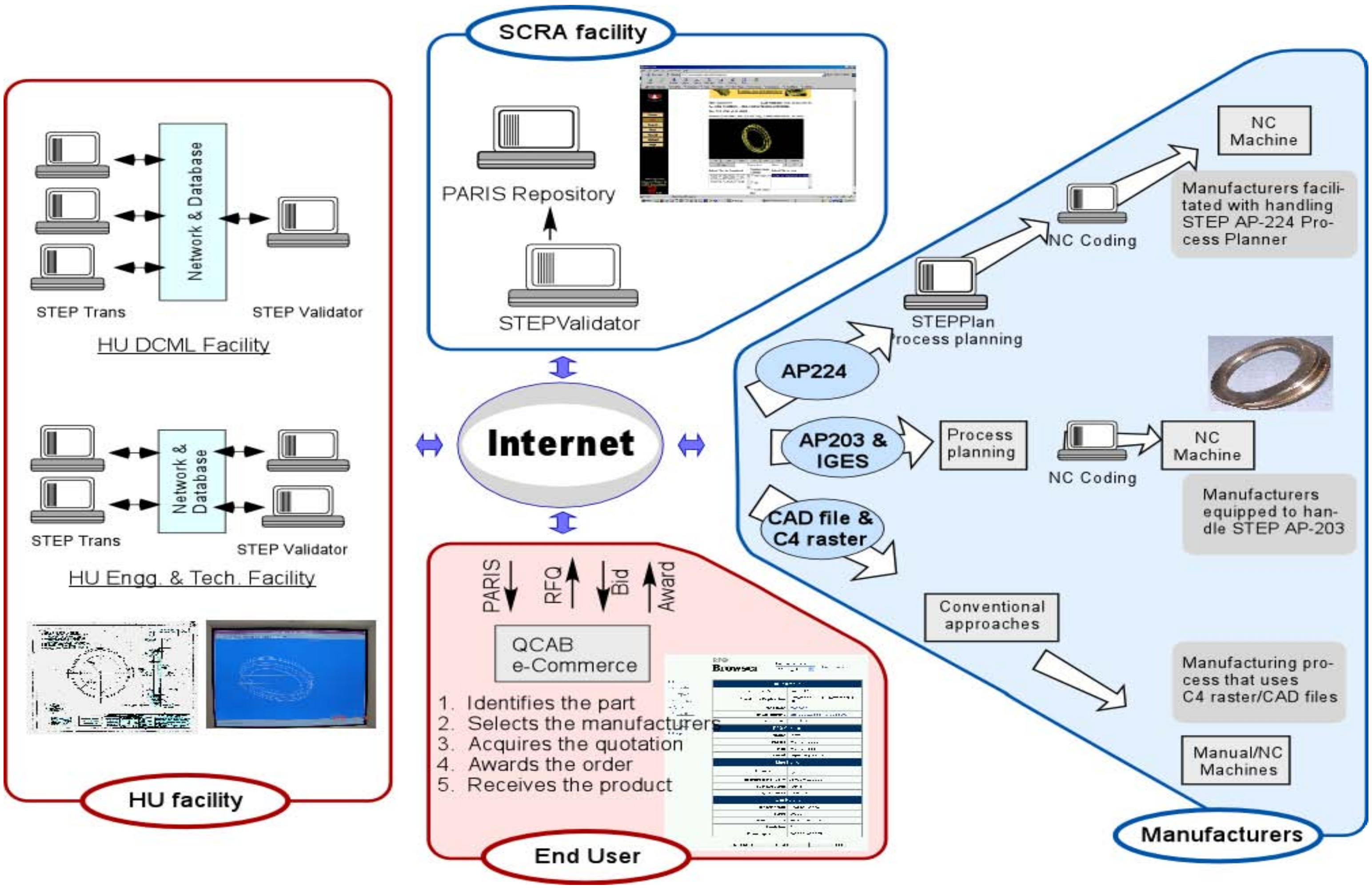

Figure 3.2 VPERC process uses the Internet for communication between different groups involved in the manufacturing process. Once the part is captured in CAD and exported as STEP and IGES files along with the TDP into a repository, the system is tuned for acquiring the part expeditiously.

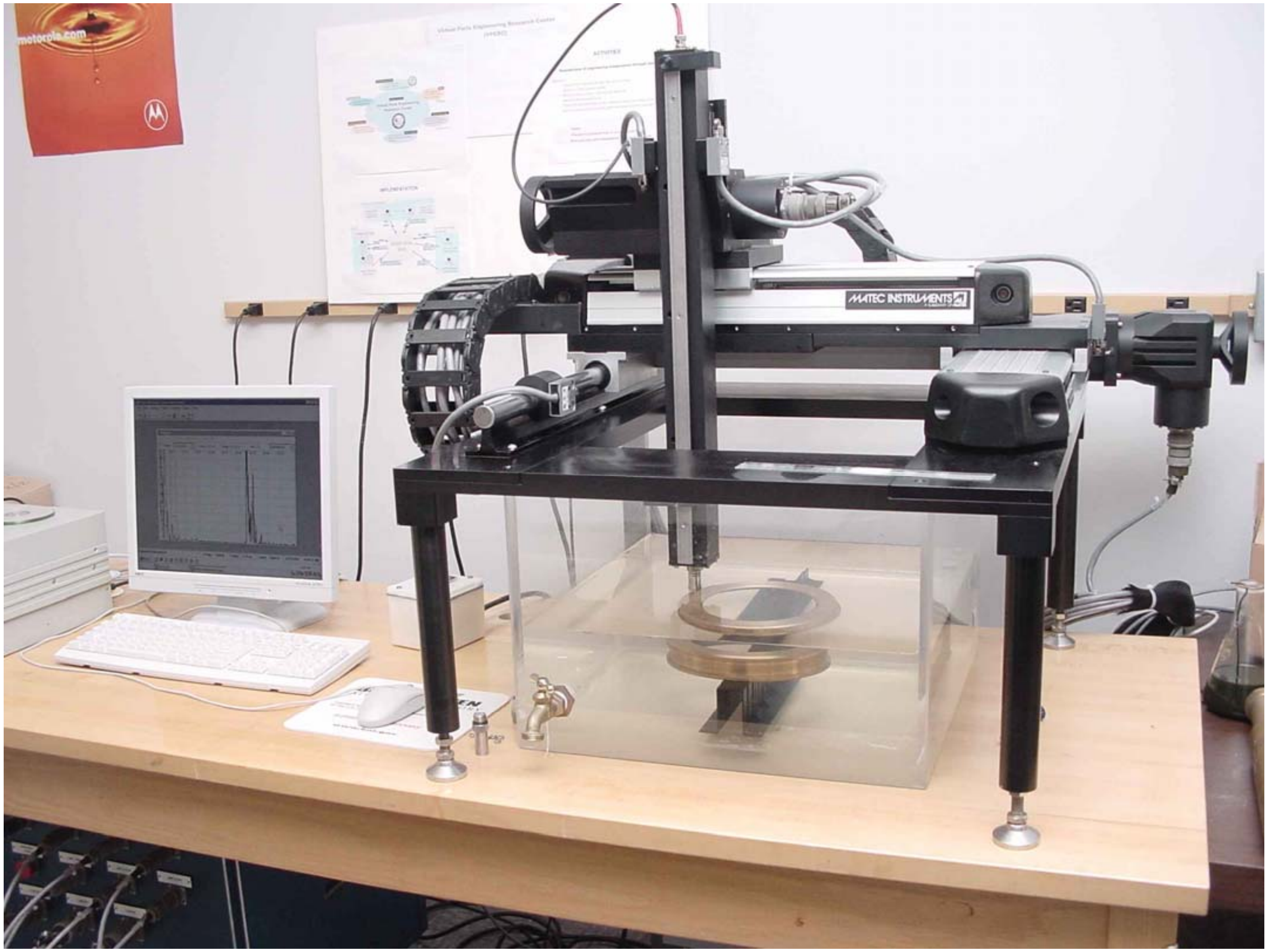

Figure 3.3 Ultrasonic testing unit with immersion tank. A ring is being subjected to the scan.

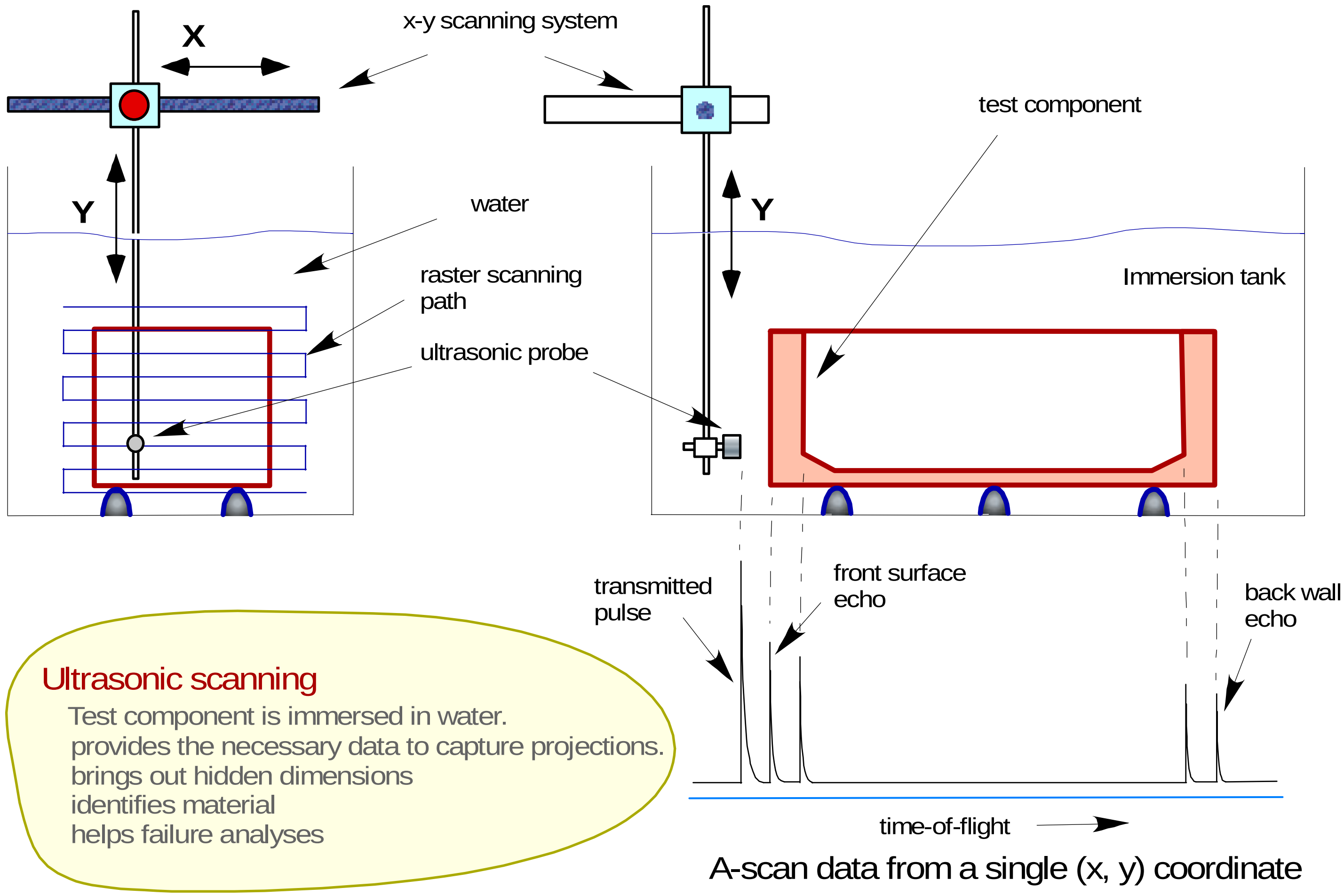

Figure 3.4 Ultrasonic methods of testing are widely used in nondestructive testing. A scanning technique has been developed to determine the geometry, dimensions and interfaces of parts. Details from even hidden regions can be acquired in most cases where conventional methods cannot be used to get the details.

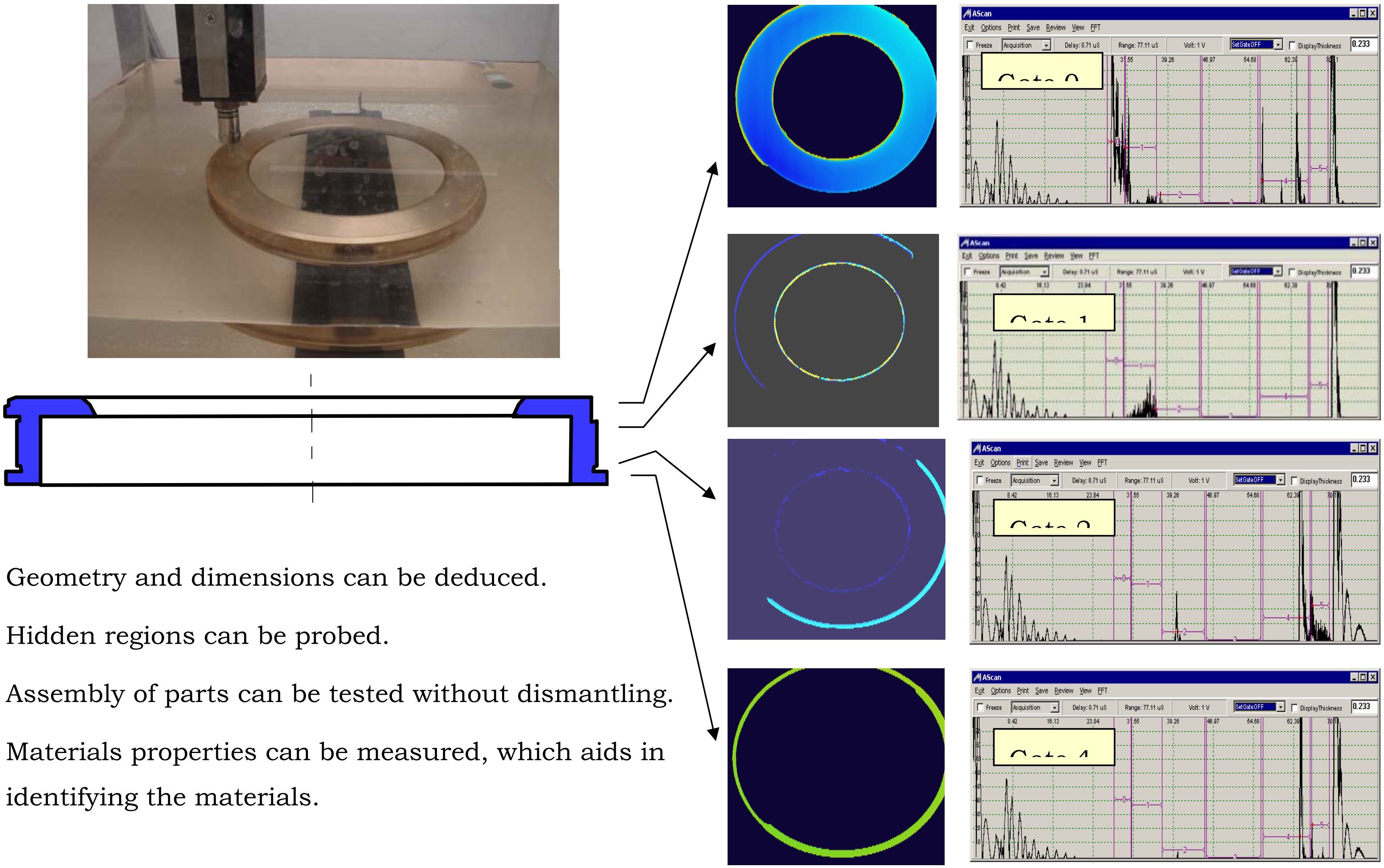

Figure 3.5 Data from different depths are being extracted in a single X-Y scanning.

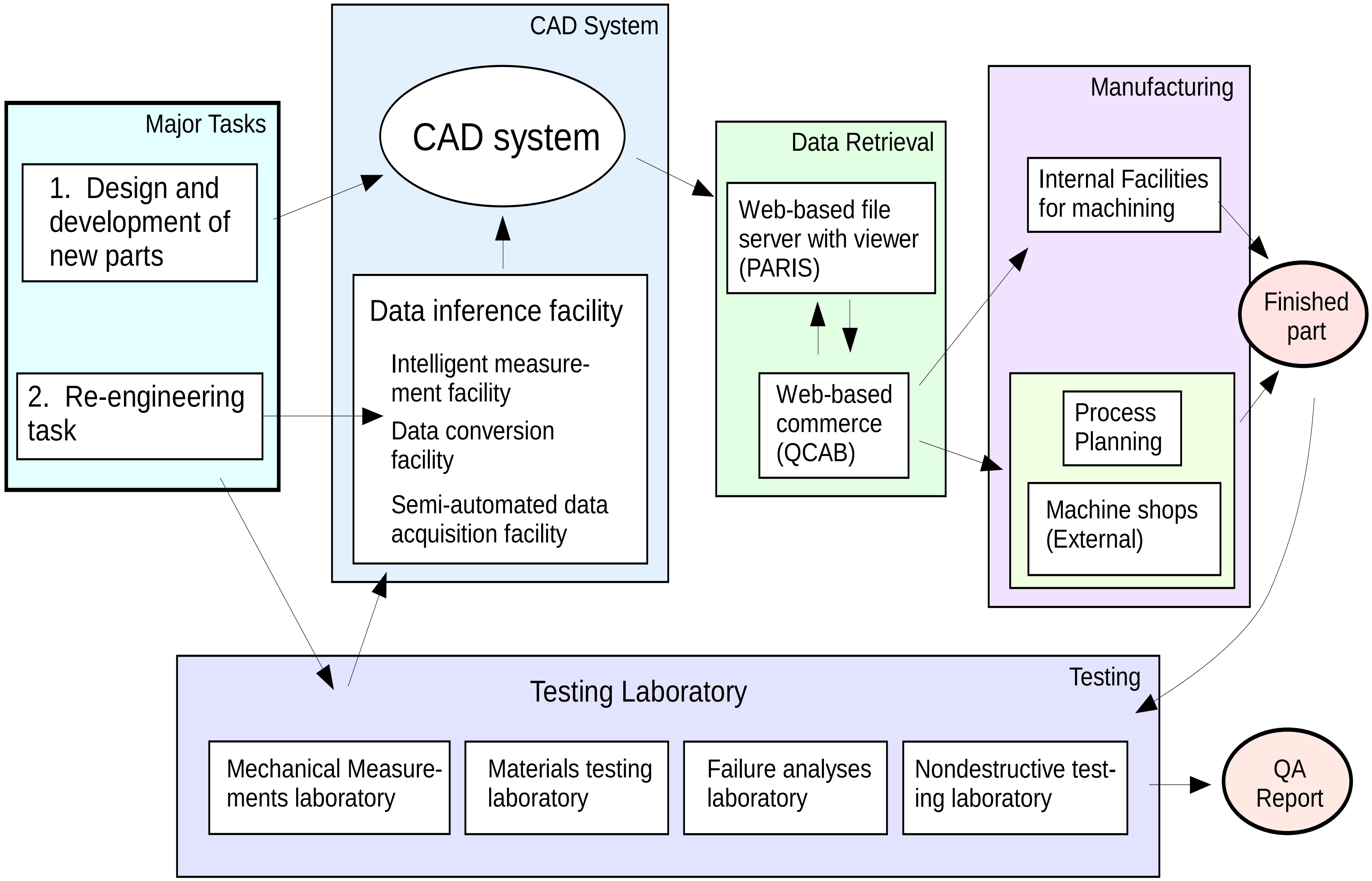

Figure 3.6 The VPERC laboratory evolved with facilities to perform reverse engineering in support of rapid parts procurement.

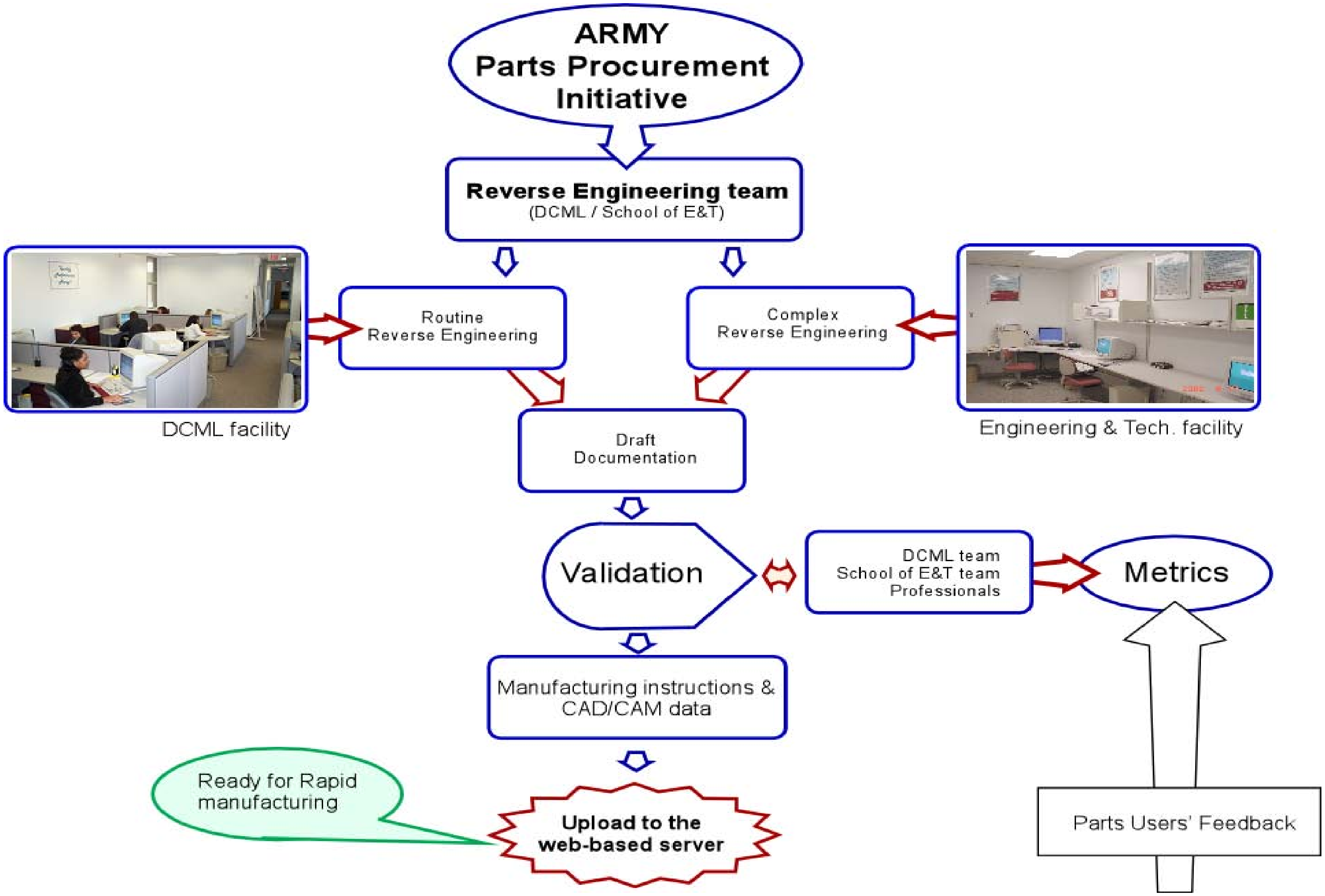

Figure 3.7 Process to carry out reverse engineering and preparation of technical data packages for the manufacture of parts, to be accomplished in partnership with a group of manufacturers.

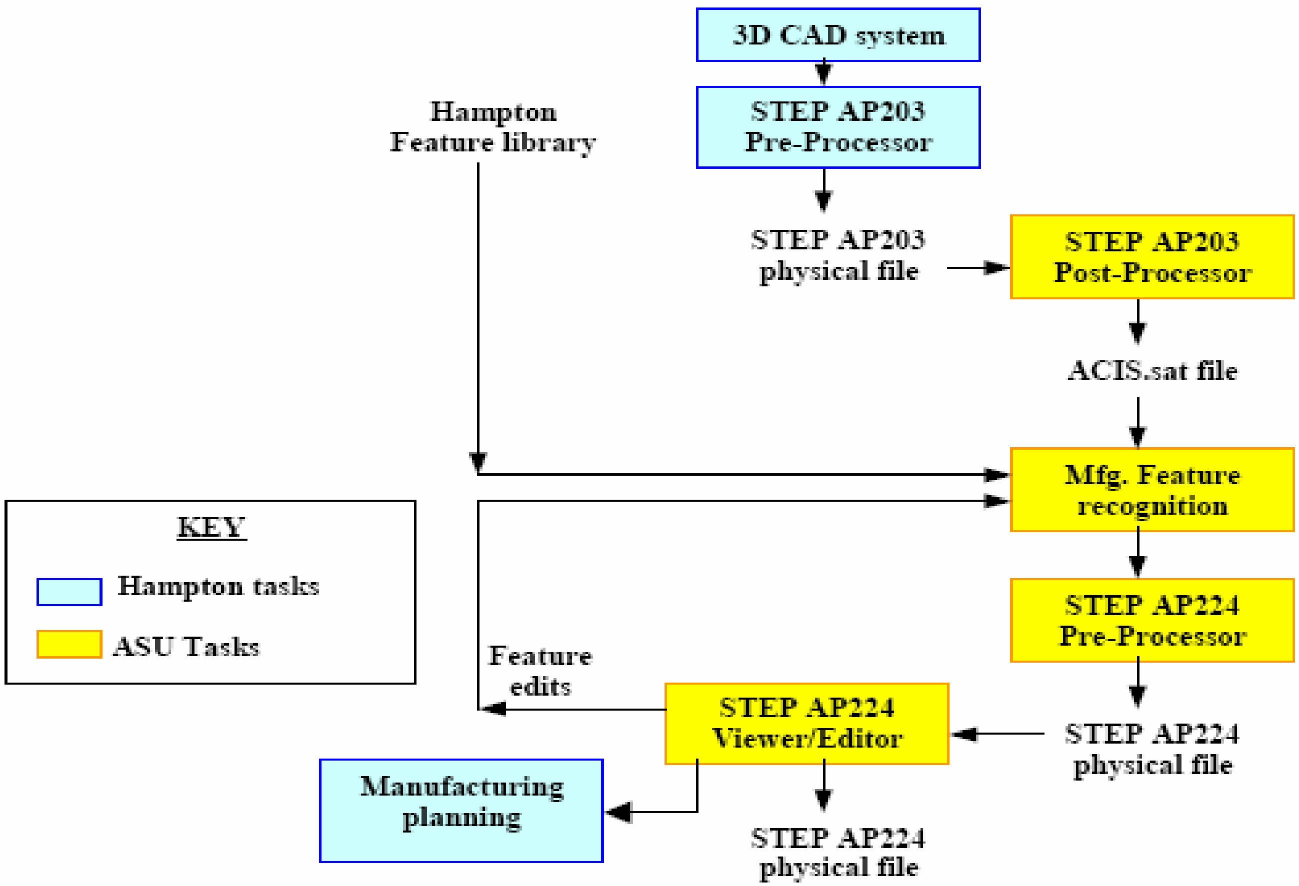

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Figure 3.8 Recognition of manufacturing features from STEP AP203 CAD models.

(Prof. J. Shah, Arizona State University – Collaborative effort ASU/HU)

Figure 4.1 Photograph of a part for reverse engineering, received from Defense Logistics Agency, DLA. This is an airspeed indicator case used in T38 aircraft.

Figure 4.2 Photograph of the part, with label.

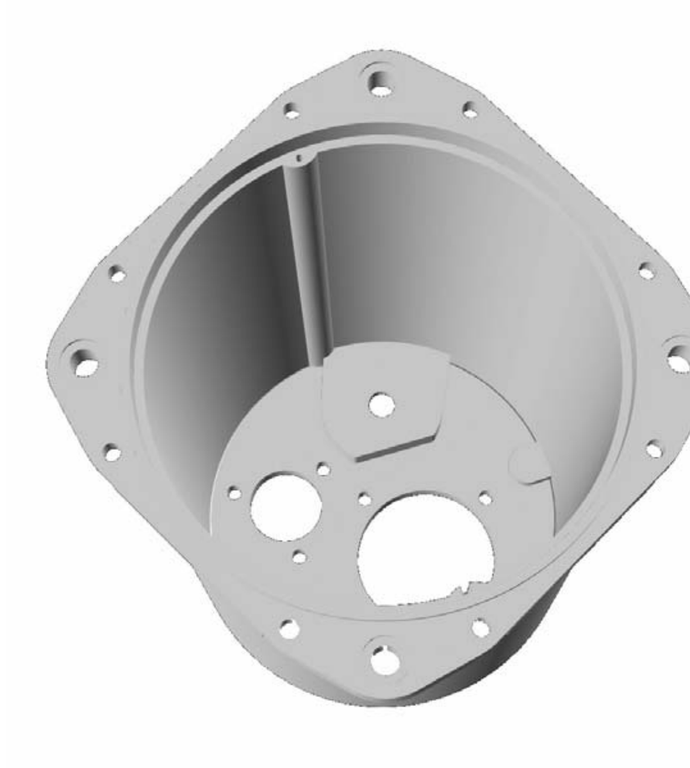


Figure 4.3 3D model of the airspeed indicator case, developed at the University of Utah.

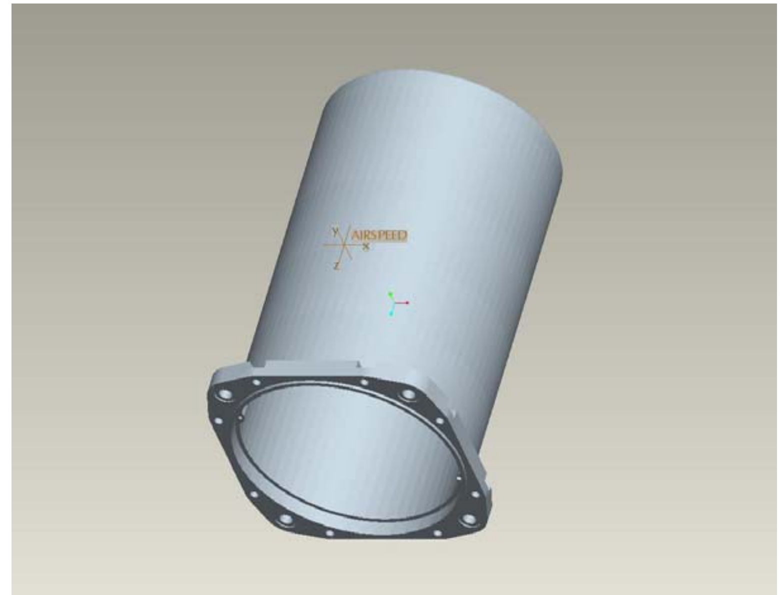
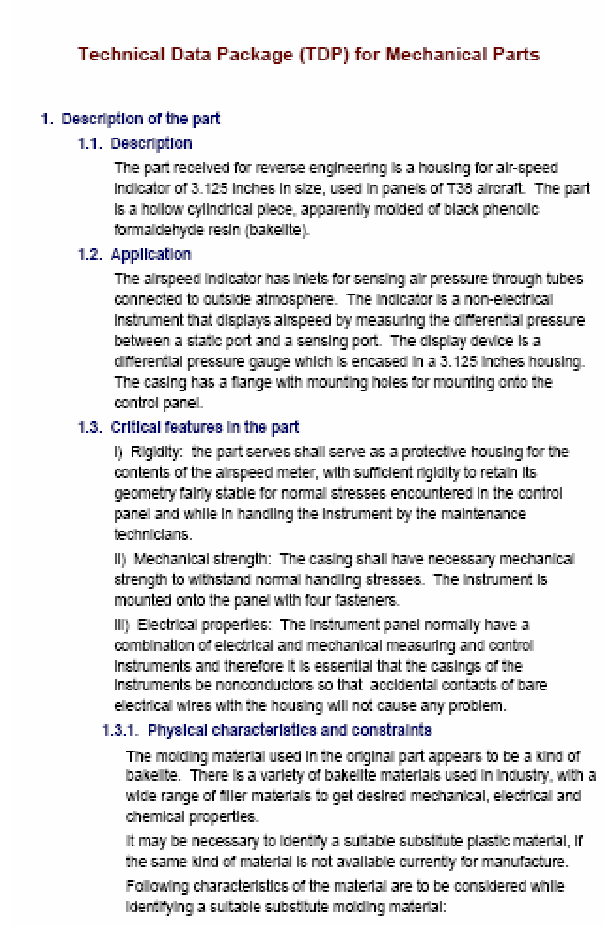


Fig. 4.4 3D model of the airspeed indicator case, developed at Utah and HU.

Figure 4.5 Photograph of the part made by Utah by fused-deposition-modeling unit (FDM).

Figure 4.6 Photograph of the part manufactured by Focus:HOPE, Detroit using Bakelite-CE.

Figure 4.7 Photograph of the part machined by the University of Utah using Delrin.



Technical Data Package (TDP) for Mechanical Parts

1. Description of the part

1.1. Description

The part received for reverse engineering is a housing for air-speed indicator of 3.125 inches in size, used in panels of T38 aircraft. The part is a hollow cylindrical piece, apparently molded of black phenolic formaldehyde resin (bakelite).

1.2. Application

The airspeed indicator has inlets for sensing air pressure through tubes connected to outside atmosphere. The indicator is a non-electrical instrument that displays airspeed by measuring the differential pressure between a static port and a sensing port. The display device is a differential pressure gauge which is encased in a 3.125 inches housing. The casing has a flange with mounting holes for mounting onto the control panel.

1.3. Critical features in the part

I) Rigidity: the part serves shall serve as a protective housing for the contents of the airspeed meter, with sufficient rigidity to retain its geometry fairly stable for normal stresses encountered in the control panel and while in handling the instrument by the maintenance technicians.

II) Mechanical strength: The casing shall have necessary mechanical strength to withstand normal handling stresses. The instrument is mounted onto the panel with four fasteners.

III) Electrical properties: The instrument panel normally have a combination of electrical and mechanical measuring and control instruments and therefore it is essential that the casings of the instruments be nonconductors so that accidental contacts of bare electrical wires with the housing will not cause any problem.

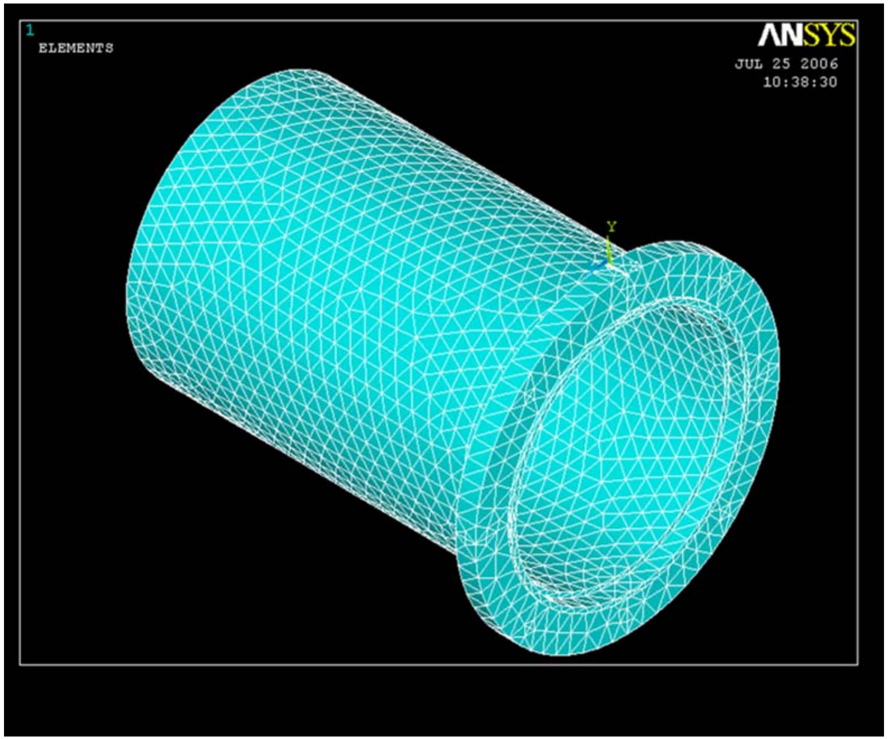
1.3.1. Physical characteristics and constraints

The molding material used in the original part appears to be a kind of bakelite. There is a variety of bakelite materials used in industry, with a wide range of filler materials to get desired mechanical, electrical and chemical properties.

It may be necessary to identify a suitable substitute plastic material, if the same kind of material is not available currently for manufacture.

Following characteristics of the material are to be considered while identifying a suitable substitute molding material:

Figure 4.8 A part of Technical Data Package (TDP) prepared for Defense Logistic Agency. Hampton Univ pre-qualified to perform reverse engineering for the DLA.



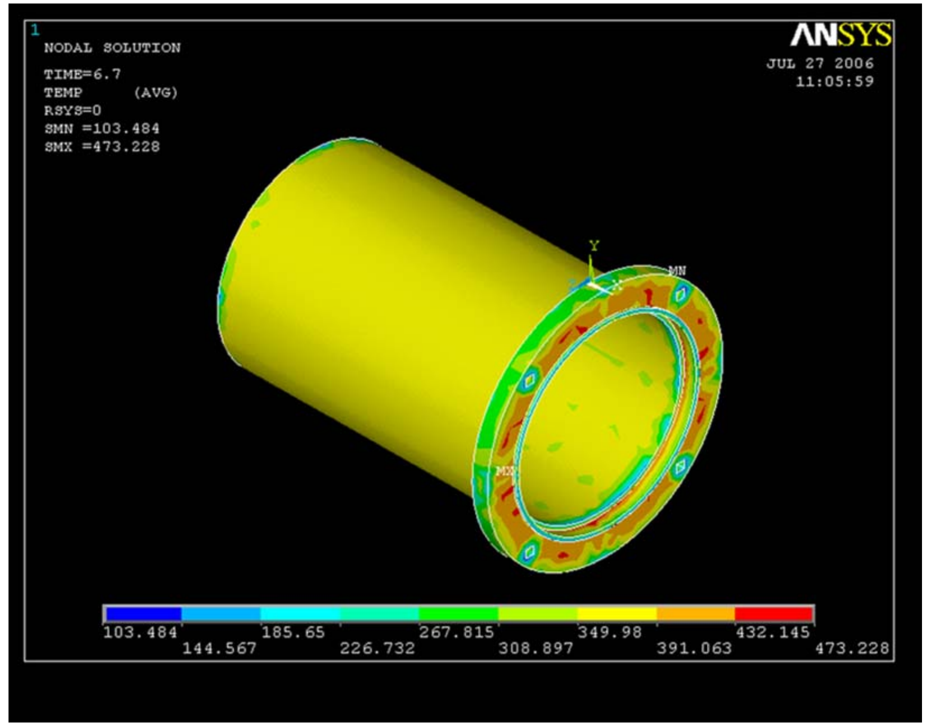


Figure 4.9 Creating a mesh for the 3D model.

Figure 4.10 Thermal analysis to study the temperature distribution during cooling in a plastic molding process.

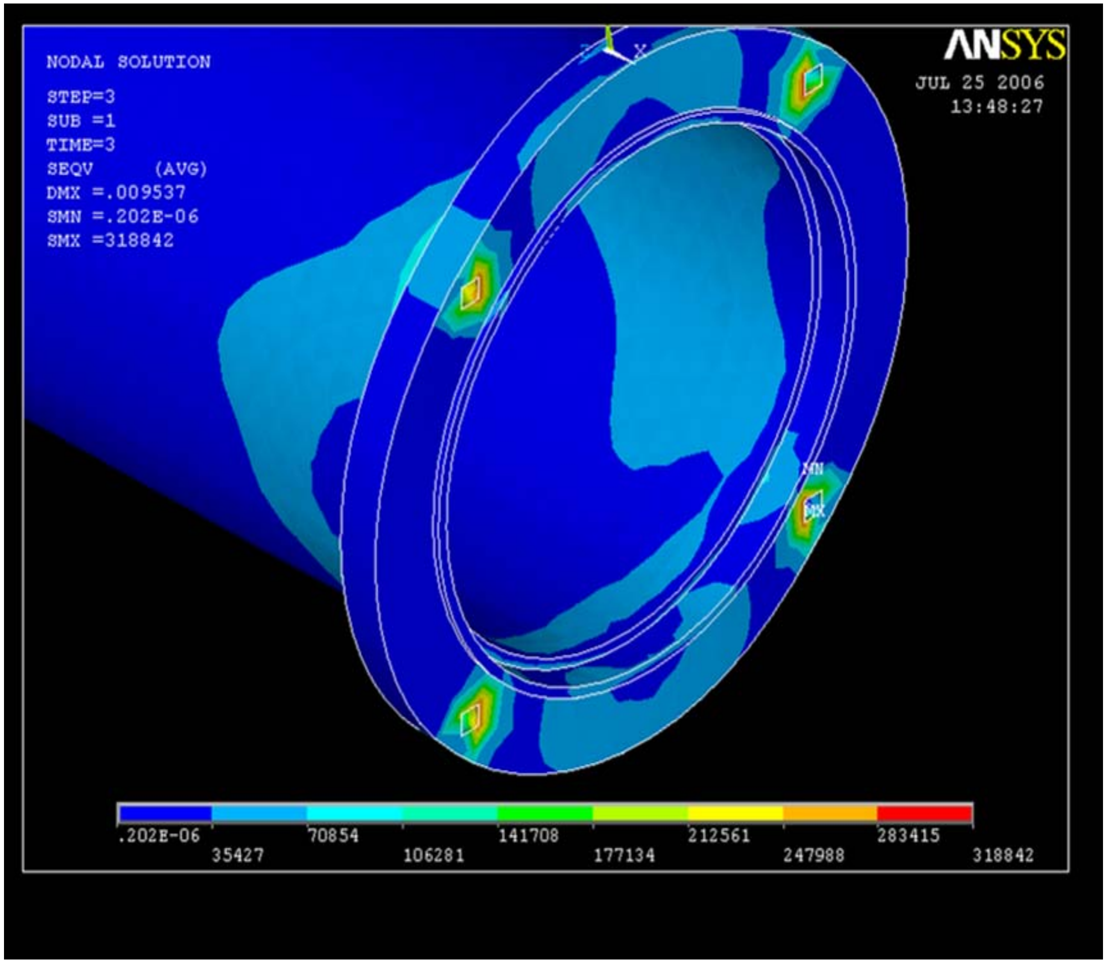
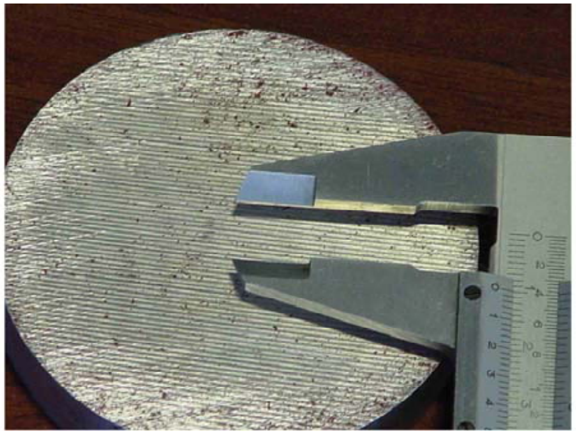
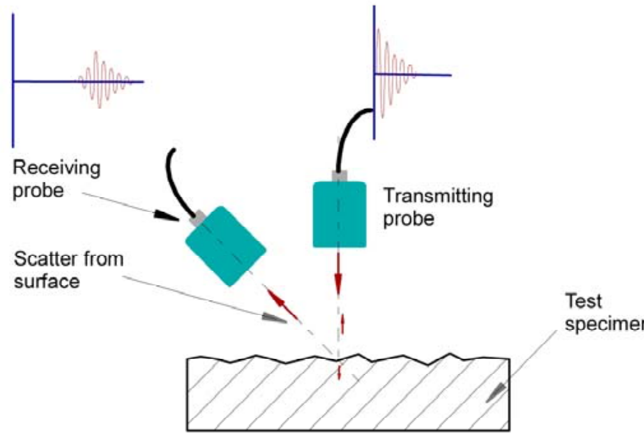
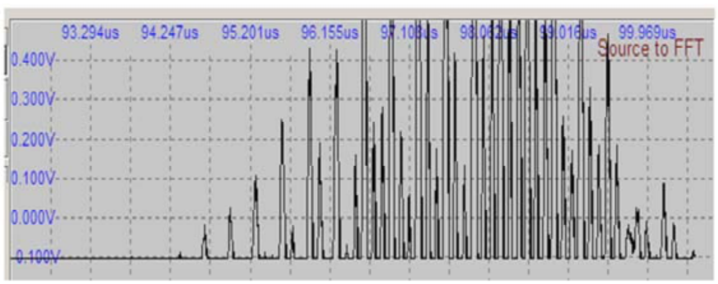


Figure 4.11 Studies on stress concentration caused by external forces.

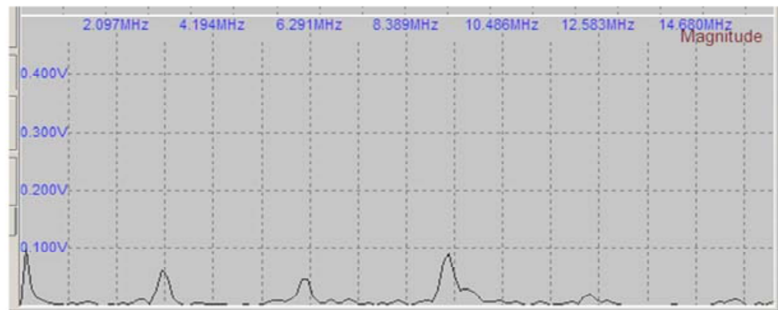


Surface with 0.82 mm scratch





Scatter waveform (Positive half)



Fourier transform of the scatter

Figure 4.12 Studies on the surface roughness of machined parts using ultrasonics.

Figure 4.13 Residual stress and texture studies using X-ray diffraction.

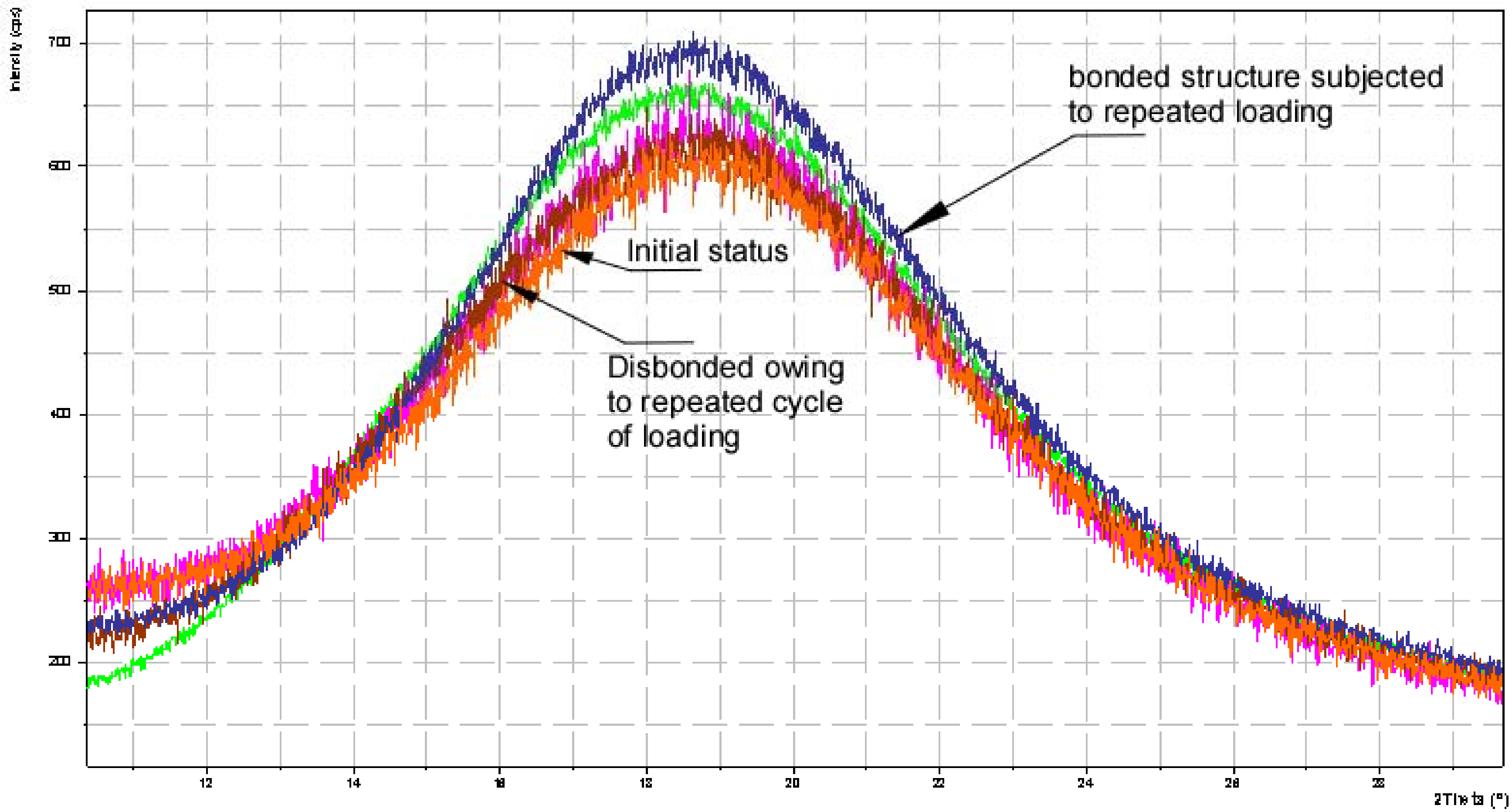


Figure 4.14 Effect of repeated stresses on line-broadening and line-shift in an X-ray diffraction study.

Adhesive bonding is used as one of the fastening methods in an assembly of parts. It provides several advantages; however, the industry needs to develop techniques to evaluate the integrity of the bond. During service, the bond may deteriorate owing to various environmental conditions such as temperature, stresses, etc. In order to understand the mechanism of disbonding or failure, samples of bonded structures are subjected to different levels of stresses and X-ray diffraction and ultrasonic tests are carried out. This figure illustrates how bond-line status influences line-shift and line-broadening.

7. References

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8. Murshed, S.M.M., Shah, J.J., Jagasivamani, V., Wasfy, A., "OAM+: An Assembly Data Model for Legacy Systems Engineering", presented at the ASME 2007 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference IDETC/CIE 2007, September 4-7, 2007.